Technical Brief

A Guide to Better Vector Network Analyzer Calibrations for Probe-Tip Measurements

A vector network analyzer (VNA), such as the HP 8510, 8753, or 87XX (includes 8719, 8720 and 8722) series, combined with Cascade Microtech's 50-ohm probes, such as the WPH, ACP, FPC, or RFIC series, provides a powerful tool for IC or module characterization, verification, or screening measurements. Calibrating the VNA with standards at the probe tips allows removal of repeatable errors from the VNA, cable, and probe losses and reflections.

Accurate calibrations require careful attention to the calibration method and elements used, probe tip physical placement accuracy, and system repeatability.

Impedance Standard Substrate (ISS) elements

An ISS contains impedance standards with known microwave characteristics, used to calibrate the system at the probe tips. The commonly used calibration standards are: short-circuit, open-circuit, load, and thru. These correspond to commonly used coaxial calibration elements (see Figure).

Cascade's ISS family includes:

Ground-Signal.....(103-726)

LRM Ground-Signal-Ground

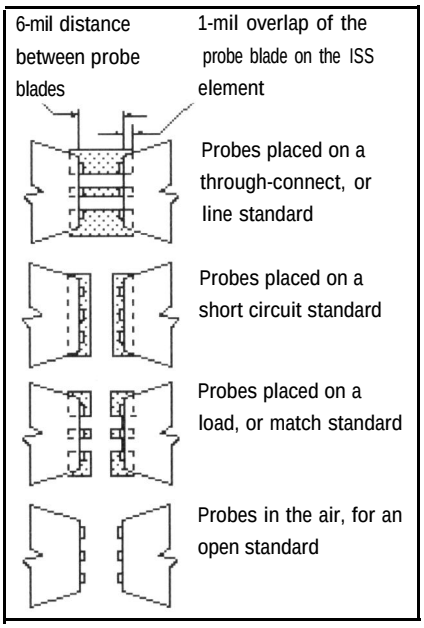
.....(101-190)

Wide-Pitch, GSG & GS

.....(106-682, 106-683)

W-band.....(104-783)

General-Purpose.....(005-016)



GSG probe tips on ISS standards.

Calibration methods reviewed

There are numerous calibration methods available. The method you choose affects the calibration. To compare two-port calibrations, please refer to the table. Here we explore the four most commonly used for wafer probe calibrations: SOLT, LRM, LRRM, and TRL.

SOLT Calibration. With SOLT, the four known references are: short, open, load, and thru.

With SOLT, you must correctly define the reference planes and parasitic inductances and capacitances for the short, open, and thru. At higher frequencies, inaccuracies in the parasitic descriptions greatly impact the accuracy of subsequent measurements.

The reference impedance in SOLT on-wafer calibrations is a physically small, trimmed, 50-ohm coplanar resistor. This resistor is best modeled as a constant resistance in series with a small, lumped reactance.

SOLT is useful for different pitched probe heads at both sides (e.g., port-1 probe, 150 μm, port-2 probe, 200 μm).

Although the dominant VNA calibration method, the SOLT calibration is not the best. Its disadvantages include:

- Determining parasitic inductances and capacitances is difficult, and their values must be consistent with respect to a single reference plane. For this reason, SOLT calibrations are best used below 20 GHz.
- Most standards to contact (typically 6).

LRM Calibration. With LRM, you need three calibration standards: a line (or thru) standard, a reflect standard, which doesn't require characterization, and two identical match (load) standards.

With an LRM calibration, the match (load) determines the reference impedance. Cascade's VNA-Cal software also determines the inductance of the match standard during the calibration process. Therefore, you only need to know its resistance (not its reactance), and you can accurately measure resistance at dc.

The LRM method's advantages include:

- Greater S-parameter accuracy
- Match is the only impedance needing self-consistent calibration algorithm definition. This helps you avoid errors caused by improperly defined open or short standards. The reference impedance is a well-behaved, trimmed coplanar resistor and thus provides a good match, enabling broadband, accurate calibrations.
- Since the reflect only needs to be identical for each port, it's easy to realize physically.
- Suitable for systems with fixed probes, since it doesn't use standards of varying separation.

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LRRM Calibration. With this LRM method variation, the unknown reflects are undefined shorts and undefined opens. You need to measure the match on only one of the two ports. The match does not need to be exactly 50 ohms.

With LRRM, you need these calibration standards: a line (or thru) standard, two different reflect standards, which do not require characterization, and a match (or load) standard.

The LRRM method has one key advantage over the LRM method: it avoids discrepancies between the load reactances seen by the port-I and port-2 probes.

TRL Calibration. Also called LRL (Line-Reflect-Line), this method uses: thru (or line), reflect, and one or more delay lines.

The TRL method uses the characteristic impedance of the delay lines to set the reference impedance (Z_0).

TRL method disadvantages include:

- You need more than one line length to cover greater than an 8:1 frequency band. This also means that impractical lengths are necessary at lower frequencies.
- Probe systems with fixed probes are unable to accommodate the additional TRL line standard length.
- Loss in the thin film coplanar waveguide and microstrip lines causes Z_0 errors. This directly affects the reference impedance of the calibration.

Cascade's recommendations for achieving the best calibration accuracy

Choose the best calibration method for your measurement. Except for special cases, the LRM or LRRM methods are superior for most on-wafer or module and interconnect measurements. The firmware of the HP 85 10 B, C supports the LRM method. And the HP 87XX VNAs support a limited LRM method. The LRRM method and LRM / LRRM load inductance corrections provide accuracy improvements over the basic LRM method, and are only available in Cascade's VIVA-calibration software (*VNACAL* and *WINCAL).*

Carefully control probe tip placement on the calibration elements. Typically, these VNAs repeatably detect phase changes due to probe displacement as small as 5 µm. All Cascade ISSs (except 005-016) include probe tip alignment patterns for accurate alignments on the calibration elements, and are configured to work with Cascade's automated calibration software module *(VNACAL-10K).* This module achieves the best probe placement repeatability and automates the whole calibration process. The operator just places the probe tips on the alignment marks and starts the routine. (Refer to *Verification of LRRM Calibrations with Load Inductance Compensation for CPW Measurements on GaAs Substrates.)*

Ensure system repeatability. The VNA, test set, coaxial cables, probes, and any adapters must all maintain very stable microwave characteristics.

Calibration Methods	VNAs	Expected Results	Typical Accuracies [3] (w/ 8510 ≤20 GHz)	Application Notes (available from Cascade)	What Cascade Recommends
SOLT	8510A, B, C 87XX	good	0.09	***On-wafer measurements using the HP 8510 Network Analyzer and Cascade Microtech waferprobes*** (HP product note 8510-6)	For probes other than GSG Only method for 8700 series SOL (no T) for single-port calibrations
LRM	8510 B, C 87xx[1]	very good	0.04	***40 GHz On- Wafer Measurements with the HP 8510 Network Analyzer and Cascade Microtech Wafer Probes***	8510 B, C two-port, front-panel calibrations with GSG probes
LRRM (w/L connection	8510 B, C	best	0.02	***LRM and LRRM Calibrations with Automatic Determination of Load Inductance***	All other measurements
TRL (LRL)[2]	8510 B, C 87XX[1]	poor	0.15	***Applying the HP 851OB TRL Calibration for Non-Coaxial Measurements*** (HP product note 8510-8)	Not generally recommended, although Cascade supports the TRL method with its 8510 calibration kit (101-338)

1 implemented through the TRL* calibration kit--not recommended for wafer calibrations
2 not recommended by HP <5 GHz
3 [S_{ij} measured — S_{ij} actual] when measuring a passive two-port

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